THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING
Department of Electrical Engineering
Space Physics Research Laboratory

SOUNDING ROCKET FLIGHT REPORT

NASA 18.22 Thermosphere Probe Experiment

Prepared on behalf of the project by

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ORA Project 07065

under contract with:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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1. INTRODUCTION

This report describes and discusses the results of the launching of NASA 18.22, a Nike-Tomahawk sounding rocket. The payload was the Thermosphere Probe (TP), described by Spencer, Brace, Carignan, Taeusch, and Niemann (1965). The TP is an instrumented ejectable package developed by this laboratory in cooperation with the Goddard Space Flight Center (G.S.F.C.), Laboratory for Atmospheric and Biological Sciences (LABS) for the purpose of studying the variability of the earth's atmospheric parameters in the altitude region between 120 and 350 km. The NASA 18.22 payload included an omegatron mass analyzer (Niemann and Kennedy, 1966); an electron temperature probe (Spencer, Brace, and Carignan, 1962); and a lunar aspect sensor. This complement of instruments permitted the determination of the molecular nitrogen density and temperature and the electron temperature in the altitude range of approximately 140 to 300 km over Wallops Island, Virginia.

A general description of the payload kinematics, orientation analysis, and data reduction is given by Taeusch, Carignan, Niemann, and Nagy (1965). The orientation analysis and omegatron data reduction were performed at this laboratory and the results are included in this report. The electron temperature data were reduced at G.S.F.C., and are not discussed in this report.

The payload described herein was one of a sequence of six launched during a 34-hr period August 26-28, 1966. Four of the six sounding rockets were launched within a 1-hr period bracketing an orbital pass of the Explorer 32 Aeronomy satellite. The purpose of the sequence of launches was to obtain relatively simultaneous data from the various sounding rocket payloads, and comparative data from the satellite. The sequence, timing, and payload descriptions of the other vehicles is described in Sounding Rocket Flight Report 07065-5-R (NASA 18.05 Thermosphere Probe Experiment). The NASA 18.22 payload was launched approximately 34 hr later than the satellite pass series for the purpose of establishing the nighttime atmosphere for diurnal variation studies.

2. GENERAL FLIGHT INFORMATION

The general flight information for NASA 18.22 is tabulated below. Table I gives flight time and altitudes of significant events occurring during flight. Some of these were estimated and are so marked. The others were obtained from the telemetry records and radar trajectory, where applicable.

Launch Date: 28 August 1966 (240th day)

Launch Time: 04:03:00.110 GMT 0003 EDT

Location: Wallops Island, Virginia (Long. 75°29'W; Lat. 37°50'N)

Apogee Parameters:

Altitude: 322.83/km
Horizontal Velocity: 454.29 m/sec
Flight Time: 280.65 sec

TP Motion:

Tumble Period: 1.5518 sec/tumble
Roll Period: 0.96 sec/roll (375°/sec)

TABLE I

TABLE OF EVENTS

Event	Flight Time (sec)		Altitude (km)	Remarks
Lift Off	0		0	
1st Stage Burn Out	4	(est)	2.5	
2nd Stage Ignition	12	(est)	8.0	
2nd Stage Burn Out	22	(est)	20.0	
Despin	42.5	(est)	68.5	
TP Ejection	44.564		73.0	
Omegatron Breakoff	59.6	(est)	105.6	
Omegatron Filaments ON M28	61.677		109.71	
Peak Altitude	280.65		322.8	
Omegatron to Mass 32	417.092		239.55	
Omegatron to Mass 16	436.995		213.42	
Omegatron to Mass 28	457.981		182.06	
L.O.S.	510	(est)	86.9	

3. LAUNCH VEHICLE

The NASA 18.22 launch vehicle was a two-stage Nike-Tomahawk combination. The first stage was the solid propellant Nike booster, which has an average thrust of 49,000 lb and burns for approximately 3.5 sec. The Nike is 135 in. long, 16.5 in. in diameter, and weighed 1325 lb unburned. The second stage was Thiokol's Tomahawk solid propellant motor. The average thrust is approximately 11,000 lb and it burns for about 9 sec. The Tomahawk is about 142 in. long, 9 in. in diameter, and weighed 530 lb unburned. The total payload, including the despin mechanism, was 78.4 in. long and weighed 132.25 lb, making the total vehicle 355 in. long and weighing 1987 lb. Drawings and photographs of the vehicle are given in Figures 1-3.

The predicted performance for this vehicle was 324 km peak altitude at 281 sec flight time. The actual performance as discussed earlier, was 322.4 km peak altitude at 280.46 sec of flight time.

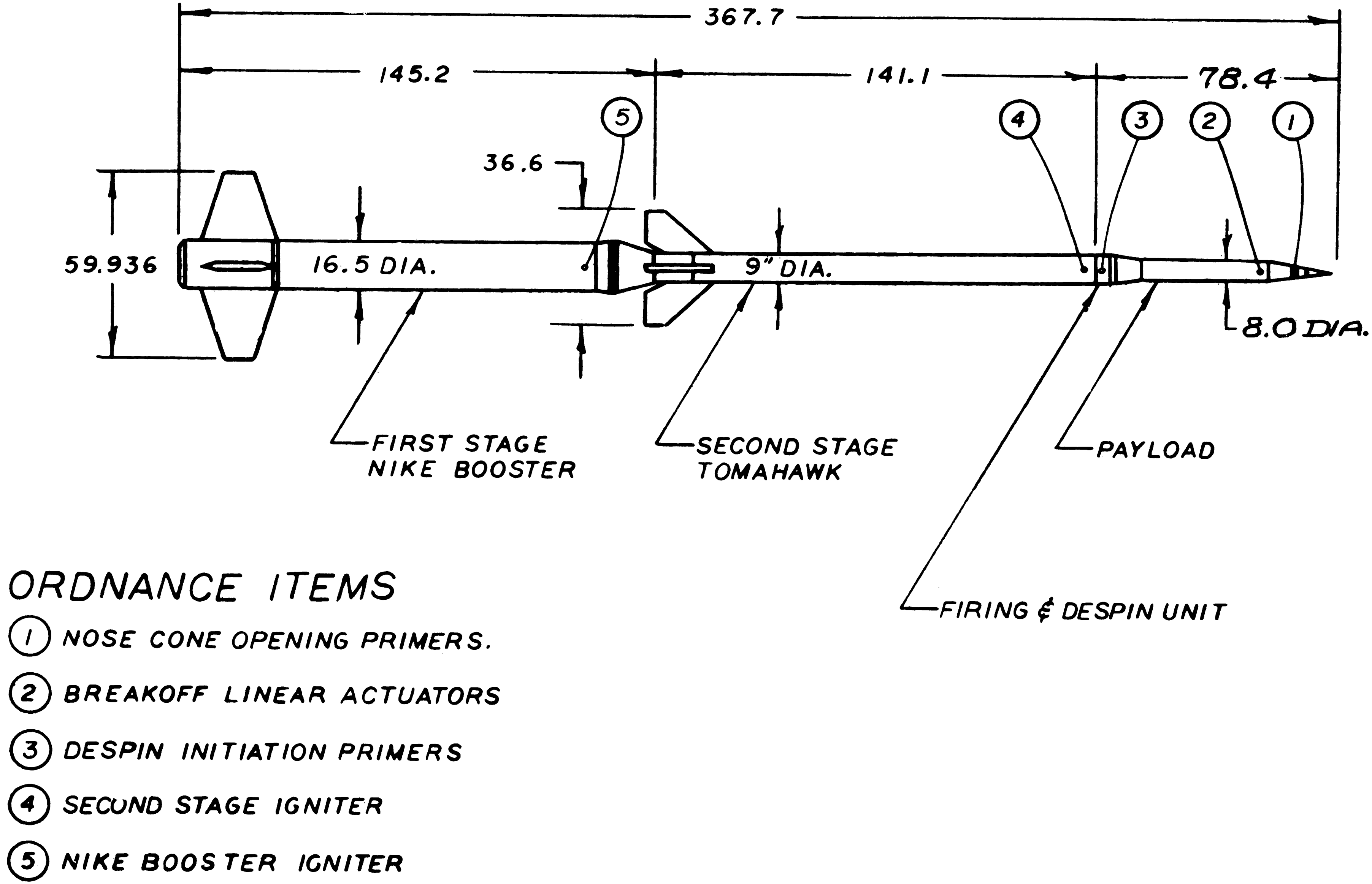


Figure 1. Nike-Tomahawk dimensions.

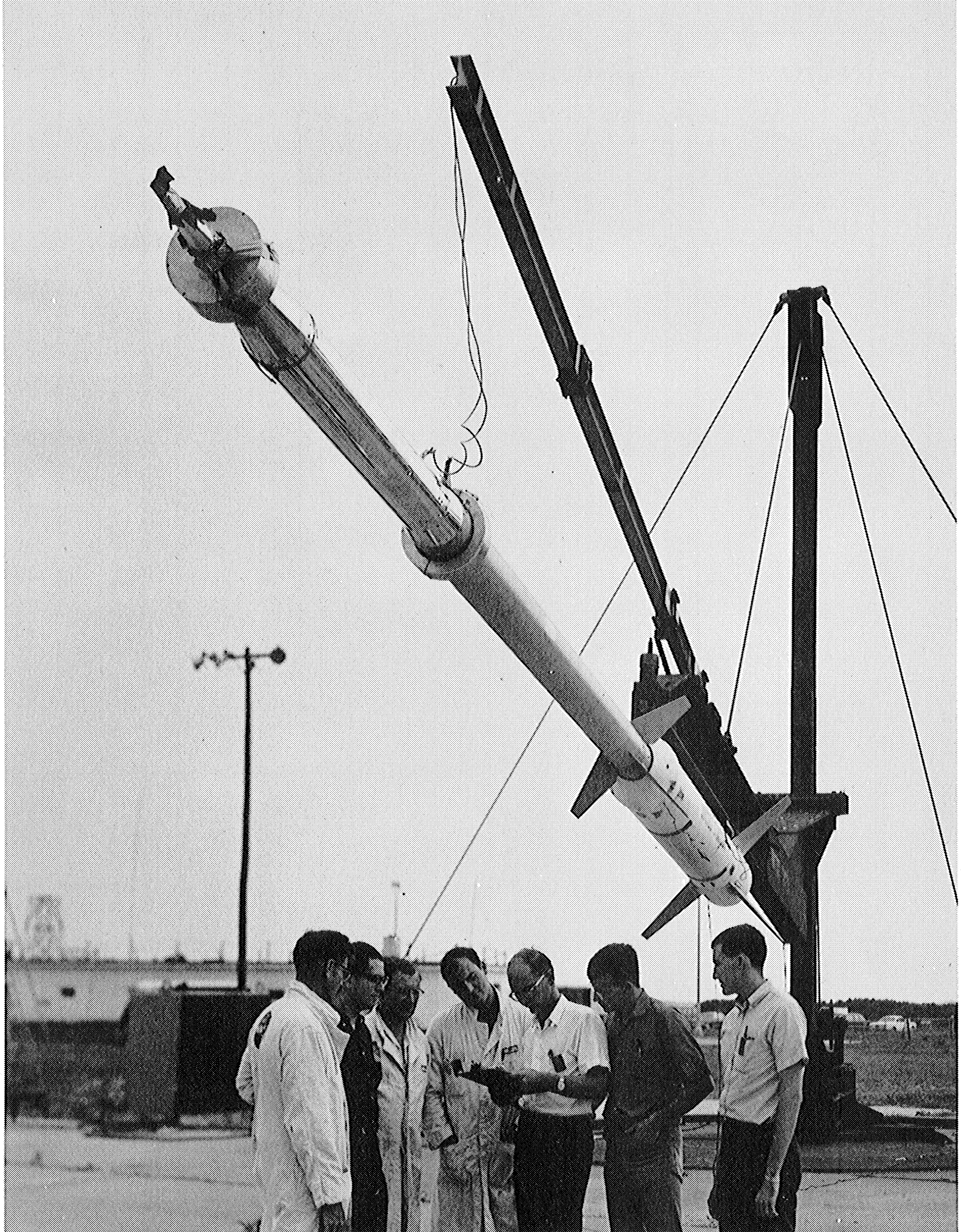


Figure 2. Nike-Tomahawk with payload.

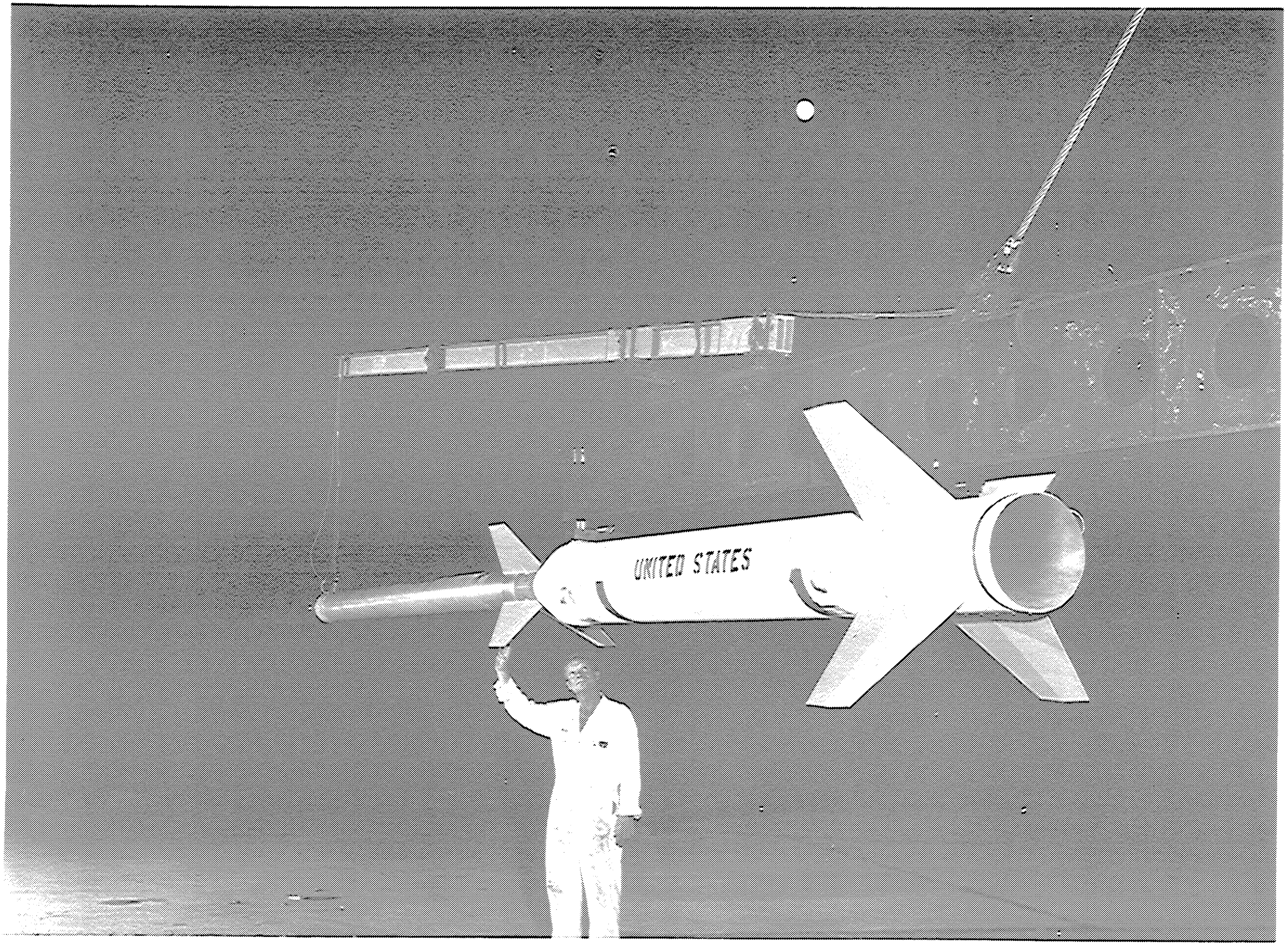


Figure 3. Nike-Tomahawk with payload.

4. NOSE CONE

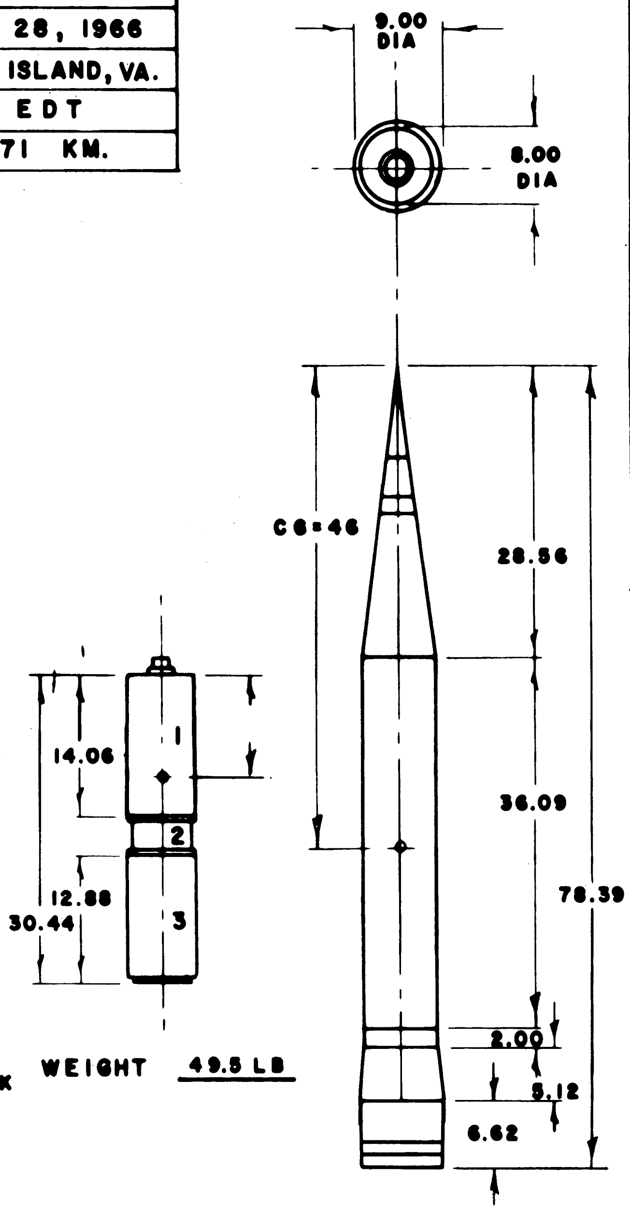
A diagram of the NASA 18.22 payload, including nose cone, despin mechanism, and adapter sections is shown in Figure 4. The weights, dimensions, and instrumentation placement are also given on the figures.

The sequence of events for which the payload is programmed was given in a previous section.

NASA	18.22
T.P. NO.	13
TYPE OF ROCKET	NIKE - TOMAHAWK
DATE OF SHOT	AUGUST 28, 1966
LOCATION	WALLOPS ISLAND, VA.
TIME	0003 EDT
ALTITUDE	320.371 KM.

RESULTS - DATA OK

MISC. NOTES - NIGHT SHOT
OMEG
E.S.P.



SECTION 1

1. OMEG ASS'Y & B O
2. OMEG ADAPTER
3. OMEG AMP
4. REG DECK
5. OM X 5 DECK
6. OSC DECK 1
7. OSC DECK 2
8. AUX DECK

SECTION 2

1. SINGLE PROBE
   BERYLLIUM COPPER
   GOLD PLATE

SECTION 3

1. TRANSMITTER & BATT. DECK
2. ESP DECK
3. SCO DECK
4. COMM DECK
5. CONTROL DECK
6. LUNAR ASPECT SENSOR

WEIGHT 49.5 LB

WEIGHT 82.75 LB

TOTAL WEIGHT OF PROBE AND NOSE CONE 132.25 LB

Figure 4. Payload diagram.

5. THE THERMOSPHERE PROBE (TP)

The TP used for the NASA 18.22 payload was a cylinder 30.44 in. long and 7.25 in. in diameter weighing 49.5 lb. The prime instruments for this payload were an omegatron mass analyzer and an electron temperature probe. Supporting instrumentation included a lunar aspect sensor for use in determining the TP aspect. The diagram in Figure 5 shows the instrumentation and supporting electronics location. Figure 6 is the system block diagram. Figure 7 is a photograph of the completely assembled TP.

5.1 OMEGATRON

The omegatron used in the payload was of the type described by Niemann and Kennedy (1966). An expanded view of the system is shown in Figure 8. Table II lists the operating parameters of the gauge and associated electronics. The characteristics of the linear electrometer amplifier current detector, used to monitor the omegatron output current, are also listed. The breakoff configuration, omegatron envelope, and magnet assembly are shown in Figures 9-11.

The calibration of the NASA 18.05, NASA 18.06, and NASA 18.22 omegatrons was performed at The University of Michigan between mid-July and mid-August 1966, and a comparison calibration was performed at G.S.F.C. in mid-August 1966. The final calibration is shown in Figure 12.

TABLE II

OMEGATRON OPERATING PARAMETERS

Omegatron Gauge Parameters	
Beam Current	2.00 μa
Electron Collector Bias	74.51 v
Filament Bias	-91.45 v
Cage Bias	- 0.216 v
Top Bias	- 0.622 v
RF Amplitude	
M28	4.00 v P-P
M32	4.00 v P-P
M16	4.00 v P-P
RF Frequency	
M28	146.34 kHz
M32	127.64 kHz
M16	252.19 kHz
Monitor	
Filament	
OFF	0.106 v
ON	3.147 v
Beam	
OFF	0.469 v
ON	4.140 v
Thermistor Pressure (Zero Pressure)	
Filament OFF	2.431 v
Filament ON	2.248 v
Bias	3.890 v
RF	
M28	3.272 v
M32	2.863 v
M16	2.333 v

Calibration

Sensitivity 2.01×10^{-5} A/T (1.67×10^{21} part/cm^3 amp)

Maximum Linear Pressure (5%) ~ 8×10^{-6} Torr.

TABLE II (Concluded)

Electrometer Amplifier

Range	Range Indicator	Range Resistor	M28ZPV
1	0.0 v	9.119×10^{9}	4.935
2	0.7 v	2.479×10^{10}	4.935
3	1.4 v	6.738×10^{10}	4.935
4	2.1 v	1.832×10^{11}	4.935
5	2.8 v	4.979×10^{11}	4.934
6	3.5 v	1.353×10^{12}	4.933
7	4.2 v	3.679×10^{12}	4.929
8	4.9 v	1.00×10^{13}	4.920

Calibrate Voltage 0.514

Miscellaneous

+28 power current all on ~330 ma
Preflight gauge pressure (N_2) ~ 6×10^{-5} Torr.
Magnetic field strength ~ 2800 gauss

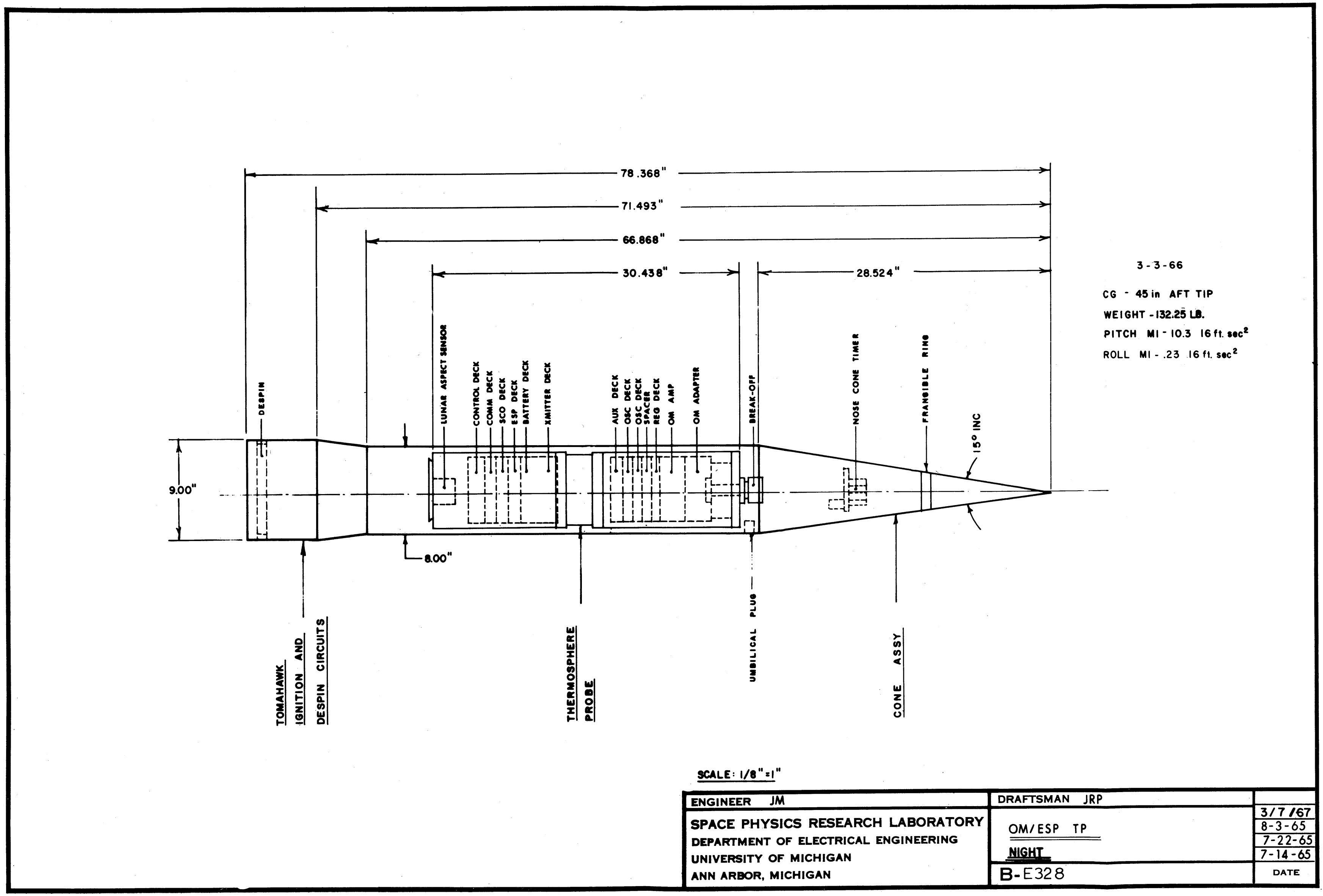


Figure 5. Thermosphere Probe instrumentation design.

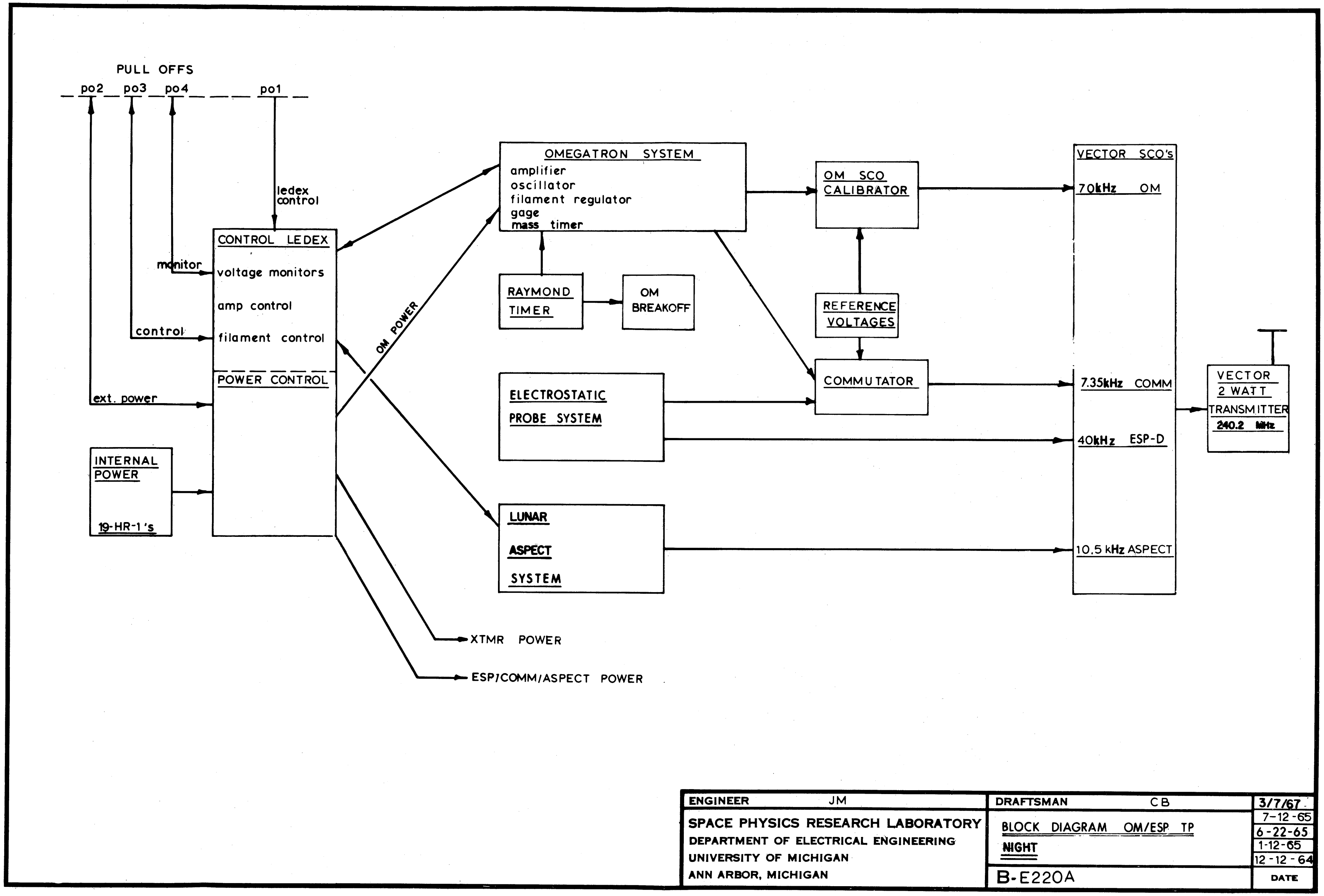


Figure 6. Block diagram.

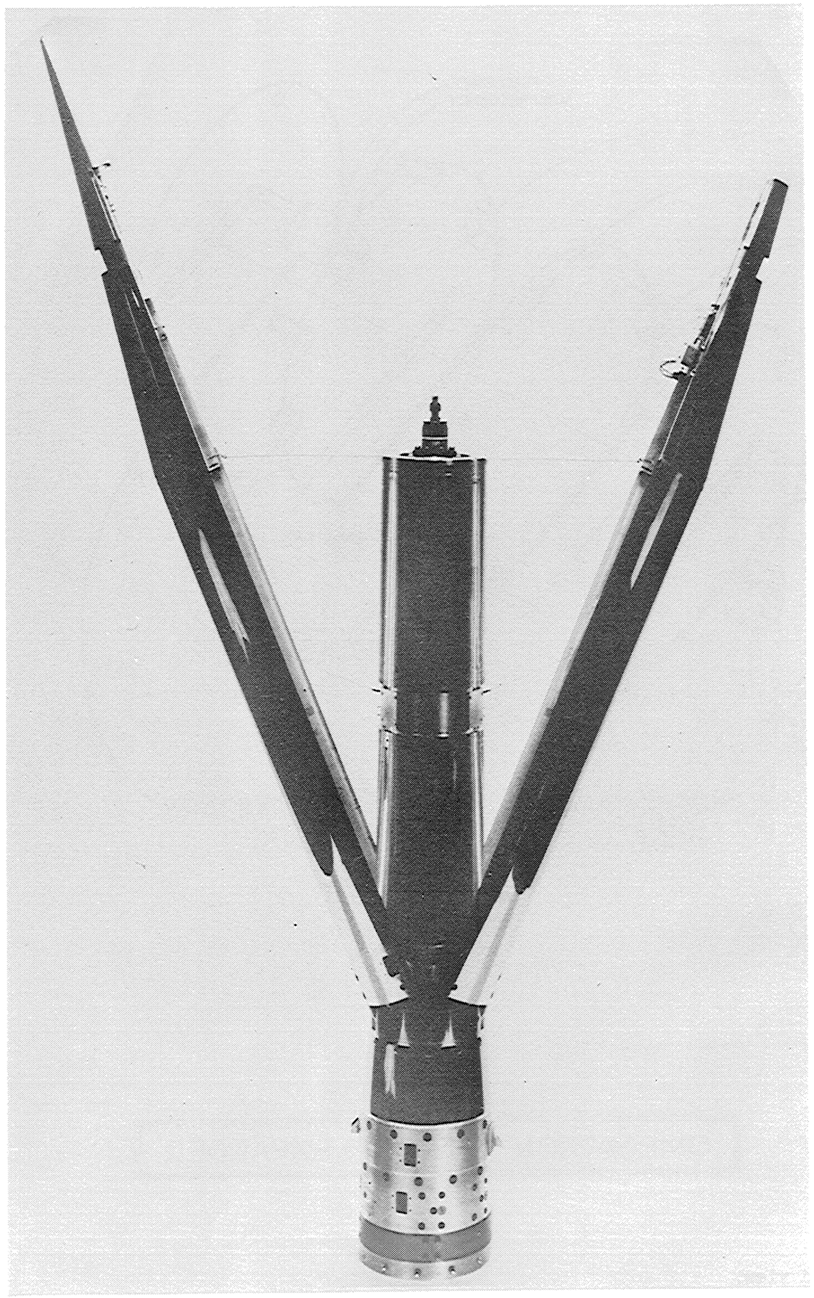


Figure 7. Thermosphere Probe.

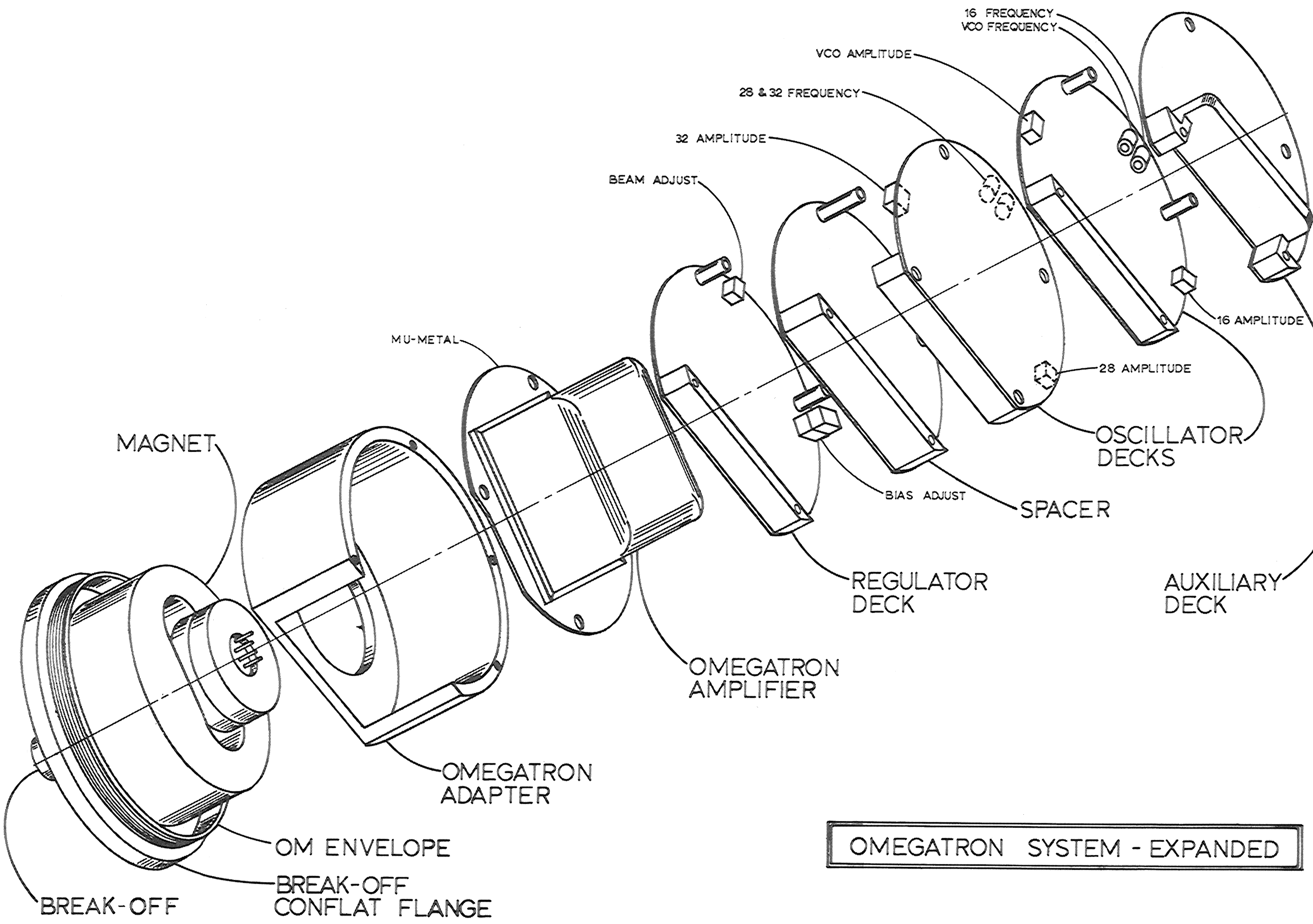
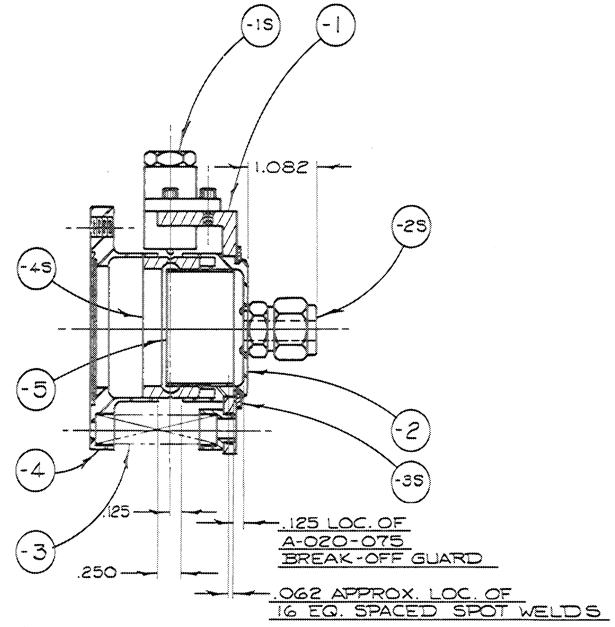
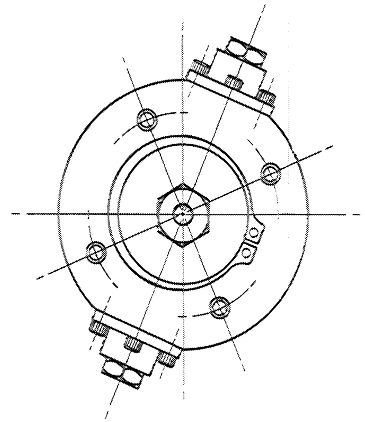


Figure 8. Omegatron expanded view.





OPERATION PROCEDURE

1. MACHINE C-020-074 - BREAK-OFF BASE WITHOUT CONFLAT GROOVE.
2. MACHINE C-020-077 - BREAK-OFF HAT & HELI-ARC WELD MODIFIED CRAWFORD SWAGELOK #600-1-4W-316 TO HAT. LEAK CHECK HELI-ARC WELD - MUST BE VACUUM TIGHT.
3. SEND DETAILS C-020-074 & C-020-077 TO COORS PORCELIN CO. TO BRAZE COORS' BREAK-OFF CERAMIC SEAL RING TO DETAILS C-020-074 & C-020-077.
4. SPOT WELD A-020-075 - BREAK-OFF GUARD TO C-020-077 - BREAK-OFF HAT AT U. OF M. AFTER BRAZING OF CERAMIC SEAL.
5. LEAK CHECK COMPLETE UNIT.
6. FINAL MACHINING OF CONFLAT GROOVE ON C-020-074 - BREAK-OFF BASE.

NO. REQ'D. L.H.	NO. REQ'D. R.H.	PART NO.	DASH NO. L.H.	DASH NO. R.H.	NAME	SIZE (MATERIAL)	DESCRIPTION (MATERIAL)
1			-4S		BREAK-OFF CERAMIC		COORS PORCELIN CO.
1		WALDES KOHINOOR #5102-168	-3S		RETAINING RING		TRUARC
1		#600-1-4W-316	-2S		CRAWFORD FITTING CO. SWAGELOK (MOD.)		
2		CONAX CORP. #1617-031-01	-1S		LINEAR ACTUATOR		
1		A-020-075	-5		BREAK-OFF GUARD		
1		C-020-074	-4		BREAK-OFF BASE		
4		A-020-079	-3		OMEGATRON BREAK-OFF SPRING		
1		C-020-077	-2		BREAK-OFF HAT		
1		C-020-078	-1		BREAK-OFF ACTUATOR ASS'Y.		

SPACE PHYSICS RESEARCH LABORATORY
DEPARTMENT OF ELECTRICAL ENGINEERING
THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

DESIGNED BY	APPROVED BY
DRAWN BY [illegible] MEYER	SCALE FULL
CHECKED BY	DATE 8-18-65

BREAK-OFF PROCEDURE ASS'Y.
OMEGATRON T.P. MOD. II

PROJECT

UNLESS OTHERWISE SPECIFIED TOLERANCES ARE:
DIM. ENDING .00 ± .030 ANGULAR DIM. ± 30 MIN.
DIM. ENDING .000 ± .010

DWG. NO. C-020-073

Figure 9. Break-off configuration.

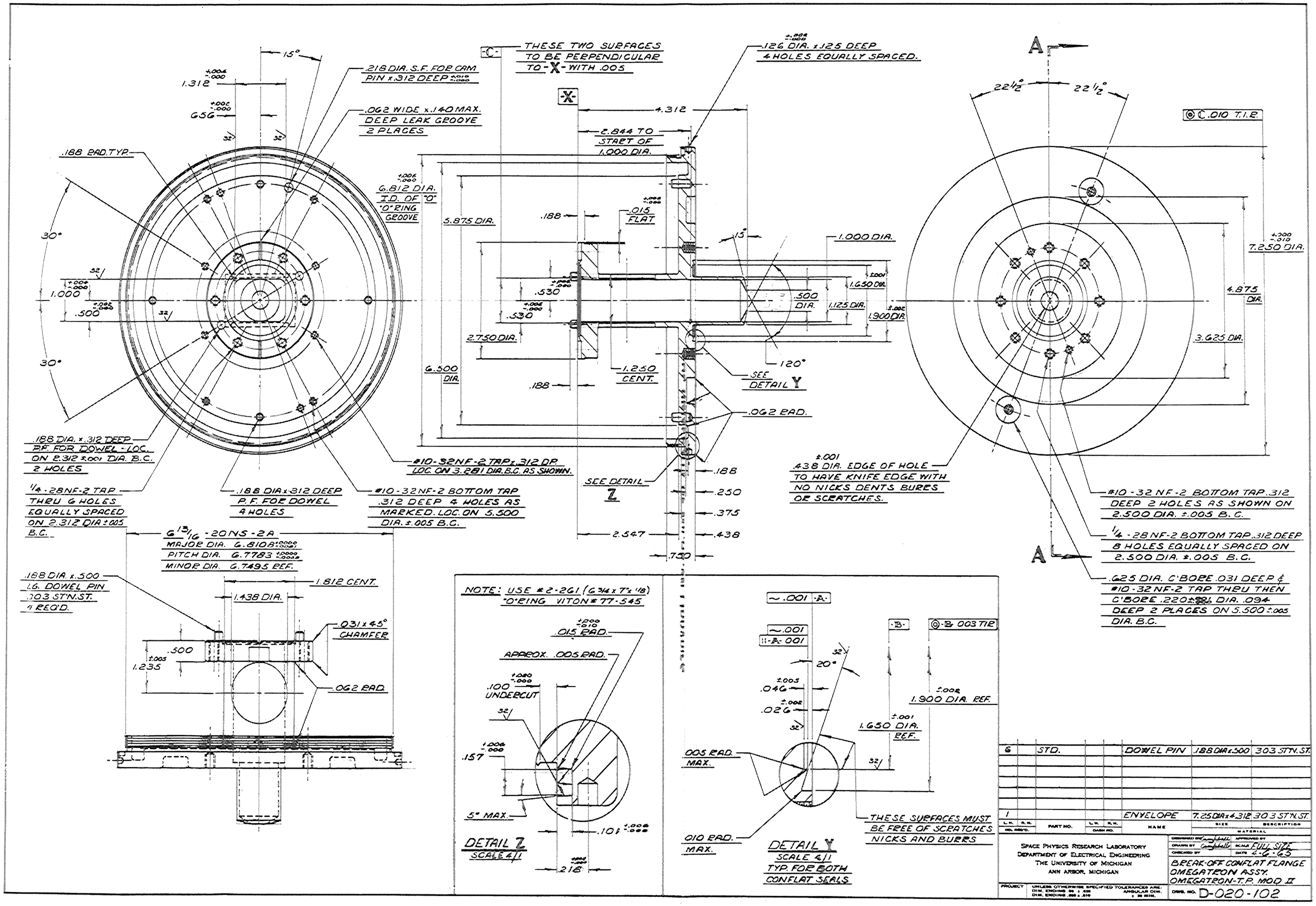


Figure 10. Omegatron envelope.

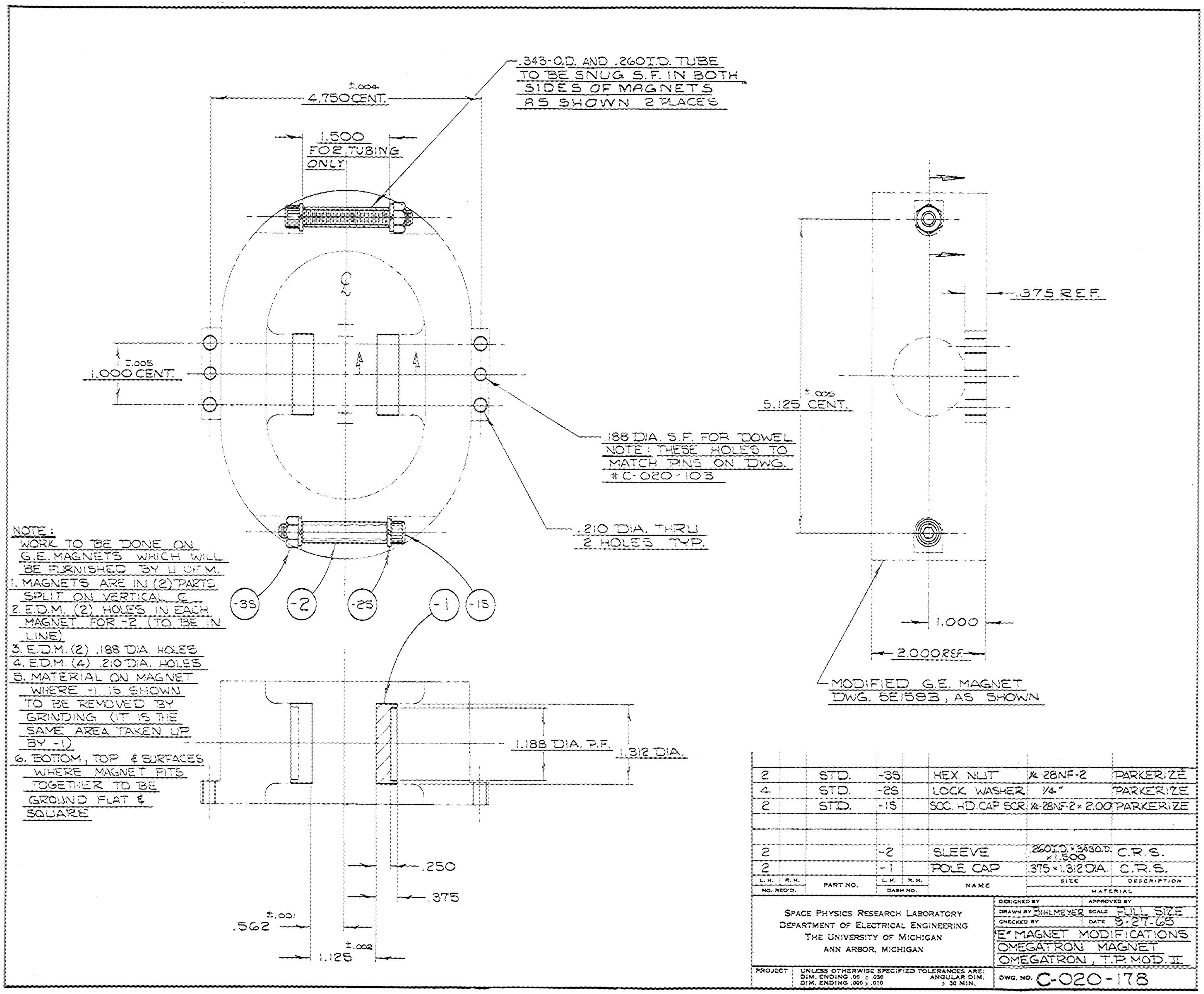


Figure 11. Magnet assembly.

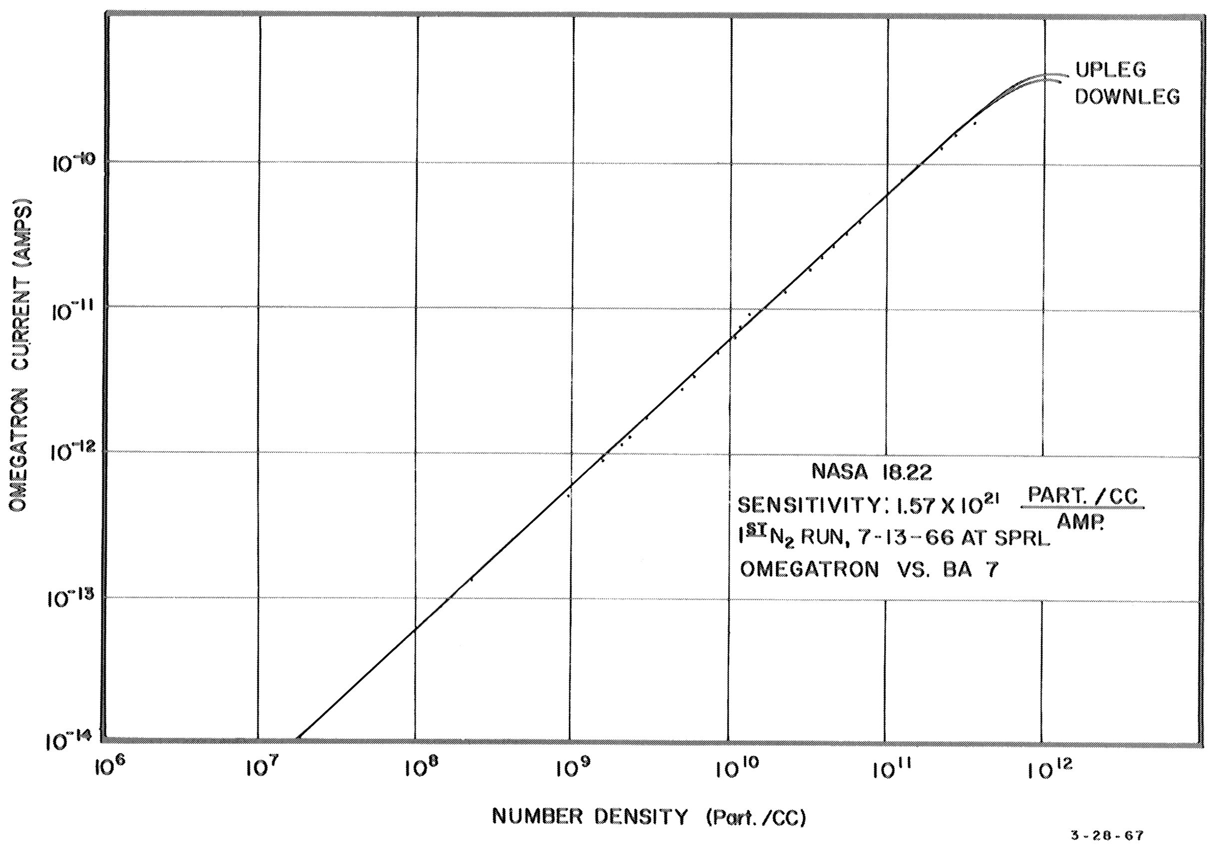


Figure 12. Omegatron calibration.

5.2 ELECTROSTATIC PROBE (ESP)

The ESP consists of a cylindrical probe placed in the plasma, and an electronics unit which measures the collected current.

The probe was gold plated beryllium copper of the same size and physical configuration as the conventional stainless steel probes. Flight data obtained from this probe was compared to data obtained from the conventional stainless steel probe flown on NASA 18.06.

The electronic unit consists of a power converter, a ΔV ramp generator, a three-range current detector, associated control logic and relays.

The specifications of the NASA 18.22 ESP are as follows:

(a) Sensitivity:

Range No. 1	10 μa full scale (4 v)
Range No. 2	1 μa full scale (4 v)
Range No. 3	0.1 μa full scale (4 v)

(b) Input Power:

1.54 watts at 28 v input

(c) ΔV Data:

HI ΔV slope	77.3 v/sec
LO ΔV slope	31.7 v/sec
ΔV period	98.5 v/sec

(d) Output:

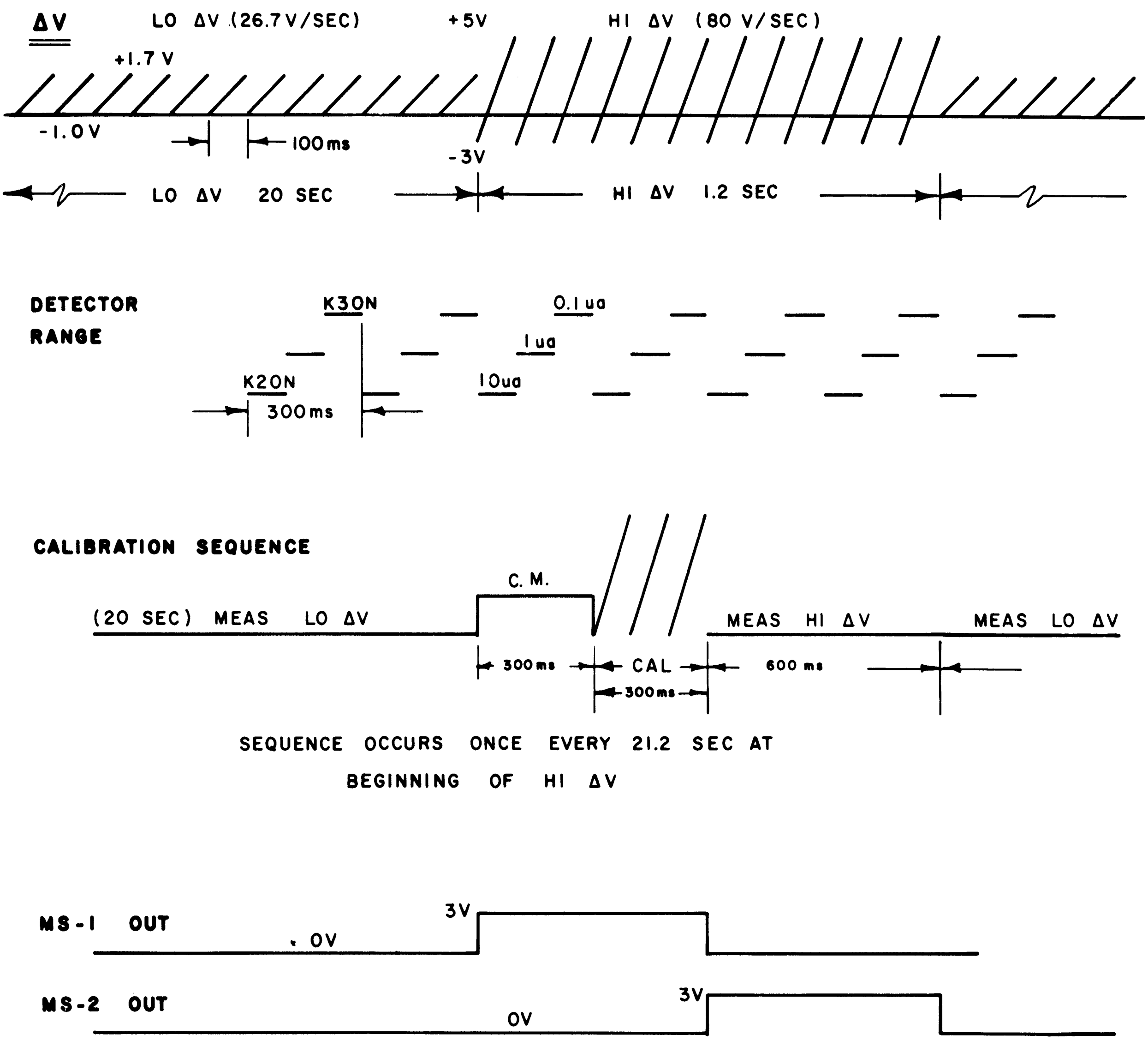
Voltage	-0.6-5.5 v
Resistance	2K
Bias Level	0.51 v

(e) System Calibration:

Calibrate every 25.2 sec
Calibrate duration 600 msec

(f) Timing

Timing and sequencing is shown in Figure 13.



ENGINEER DC

DRAFTSMAN EBR

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ANN ARBOR, MICHIGAN

TIMING
ESP DECK NASA 18.22

B-E-395

3-16-66
DATE

Figure 13. ESP timing and sequencing.

5.3 SUPPORT MEASUREMENTS AND INSTRUMENTATION

5.3.1 Lunar Aspect Determination System

The NASA 18.22 TP utilized a lunar aspect sensor identical to the ones described previously (NASA 6.11 and NASA 18.02 Thermosphere Probe Experiments). The system functioned properly throughout the flight and the aspect was determined to an accuracy of approximately ±5°. The particulars of the data reduction are described by Taeusch, et al. (1965). The velocity vector reference technique was used for this payload.

5.3.2 Telemetry

The payload data were transmitted in real time by a four-channel PAM/FM/FM telemetry system at 240.2 MHz with a nominal output of 2.5 watts. The telemetry system used four subcarrier channels, assigned as outlined below.

Transmitter: Driver TRPT-250 Serial No. 2712
Power Amplifier TRFP-2V-1 Serial No. 499
Mixer Amplifier TA58 Serial No. 1062

Subcarrier Channels (SCO-Type TS58)

IRIG Band	Serial No.	Center Frequency	Nominal Frequency Response	Function
11	2479-25	7.35 kHz	110 Hz	30 rps PAM Data
12	2484-25	10.5 kHz	160 Hz	Lunar Aspect Data
16	2500-25	40 kHz	600 Hz	Electrostatic Probe Data
18	2507-25	70 kHz	1050 Hz	Omegatron Data

Instrumentation power requirements totaled approximately 30 watts, which was supplied by a Yardney HR-1 Silvercell battery pack of a nominal 28-v output.

5.3.3 Housekeeping Monitors

Outputs from various monitors throughout the instrumentation provide information bearing on the operations of the electronic components during flight. These outputs were fed to a thirty segment commutator which ran at 1 rps. The commutator assignments are as follows.

1. Omegatron Range
2. Omegatron Output
3. Omegatron Filament Monitor
4. Omegatron Beam Current Monitor
5. Omegatron Bias Monitor
6. Omegatron RF Monitor
7. Thermistor—Omegatron Pressure
8. Thermistor—Omegatron Gage Temperature
9. Thermistor--Omegatron Amplifier Temperature
10. Thermistor—Omegatron Filament Regulator Temperature
11. Thermistor—Oscillator Temperature
12. Thermistor—Transmitter Temperature
13. Open
14. Open
15. Battery Voltage Monitor
16. Position Monitor—(Ground Control)
17. Open
18. Open
19. Open
20. Open
21. Open
22. Open
23. Open
24. 0 v Calibrate
25. 1 v Calibrate
26. 2 v Calibrate
27. 3 v Calibrate
28. 4 v Calibrate
29. 5 v Calibrate
30. 5 v Calibrate (frame sync.)

6. ENGINEERING RESULTS

The NASA 18.22 payload was essentially identical to that flown on NASA 18.02. As is described throughout this report, all systems functioned properly and complete data acquisition was accomplished.

7. DATA ANALYSIS

The telemetered data were recorded on magnetic tape at the Wallops Island Main Base and the G.S.F.C. Station A, ground station facilities. Appropriate paper records were made from the magnetic masters, facilitating quick look evaluation. The aspect data were reduced to engineering parameters from paper records. The omegatron and housekeeping data were reduced by computer techniques from the magnetic tapes.

Tracking data for trajectory determination were obtained from the FPQ-6 and FPS-16 radar facilities at Wallops Island. Tabulated reduced trajectory data were furnished by Wallops Island.

7.1 TRAJECTORY

The trajectory and velocity information used to determine aspect, density, and temperature data as a function of altitude were obtained by fitting a smooth theoretical trajectory to the radar trajectory data. The theoretical trajectory is programmed for computer solution similar to that described by Parker (1962). The output format is shown in Figure 14. The analysis of minimum angle of attack (α) as described by Taeusch, et al. (1965) is also incorporated in the program and the output of the computer furnishes α and cos α vs. time, altitude, etc. A plot of the NASA 18.22 α vs. altitude is given in Figure 15.

7.2 AMBIENT N_2 DENSITY

The neutral molecular nitrogen density was determined from the measured gauge partial pressure as described by Spencer, et al. (1965, 1966), using the basic relationship:

$$n_{a_{N_2}} = \left(\frac{\Delta n_i u_i}{2\sqrt{\pi}\, V \cos \alpha} \right)_{N_2} K(S,\alpha)$$

where

$n_{a_{N_2}}$ = ambient N_2 number density

Δn_i = maximum minus minimum gauge number density during one tumble

u_i = $\sqrt{2kTi/m}$ most probable speed of particle inside gauge

NASA 18.22 CORRECTED TRAJECTORY 3/8/67

LAUNCH TIME (GMT)

YEAR	1966
DAY	240
HOUR	4
MINUTE	3
SECOND	.110

INITIAL CONDITIONS

TIME	56.000	SECONDS FROM LAUNCH
ALTITUDE	322816.0	FT
RANGE	70118.0	FT
VELOCITY	6828.3	FT/SEC
FLIGHT PATH ANGLE	76.6587	DEGREES UP FROM LOCAL HORIZONTAL PLANE
AZIMUTH	141.4345	DEGREES EAST OF LOCAL NORTH
LONGITUDE	-75.3313	DEGREES (+EAST)
LATITUDE	37.6879	DEGREES (+NORTH)

CONE CORRECTION 6.50

MOMENTUM VECTOR INPUT BY SPECIFYING PHI LS = 238.0 AND THETA LS = 40.0
COMPUTED MOMENTUM VECTOR IN EARTH FIXED COORDINATES IS .174334 -.981002 -.085108

MOMENTUM VECTOR INPUT BY SPECIFYING PHI LS = 242.0 AND THETA LS = 40.0
COMPUTED MOMENTUM VECTOR IN EARTH FIXED COORDINATES IS .209082 -.976228 -.057130

PEAK PARAMETERS

TIME	ALTITUDE F ALTITUDE M	ALPHA	V*COS ALPHA	PHI V	RANGE F RANGE M	VELOCITY F VELOCITY M	VXFX VYFX	VZFX	AZIMUTH ELEVATION	LATITUDE LONGITUDE
280.65	1059152 322830	58.59 60.76	236.79 221.89	-171.95 -174.90	398059 121328	1490.47 454.29	848.92 -1224.69	-27.39	146.037 .000	36.960 -74.669

Figure 14. Trajectory output format.

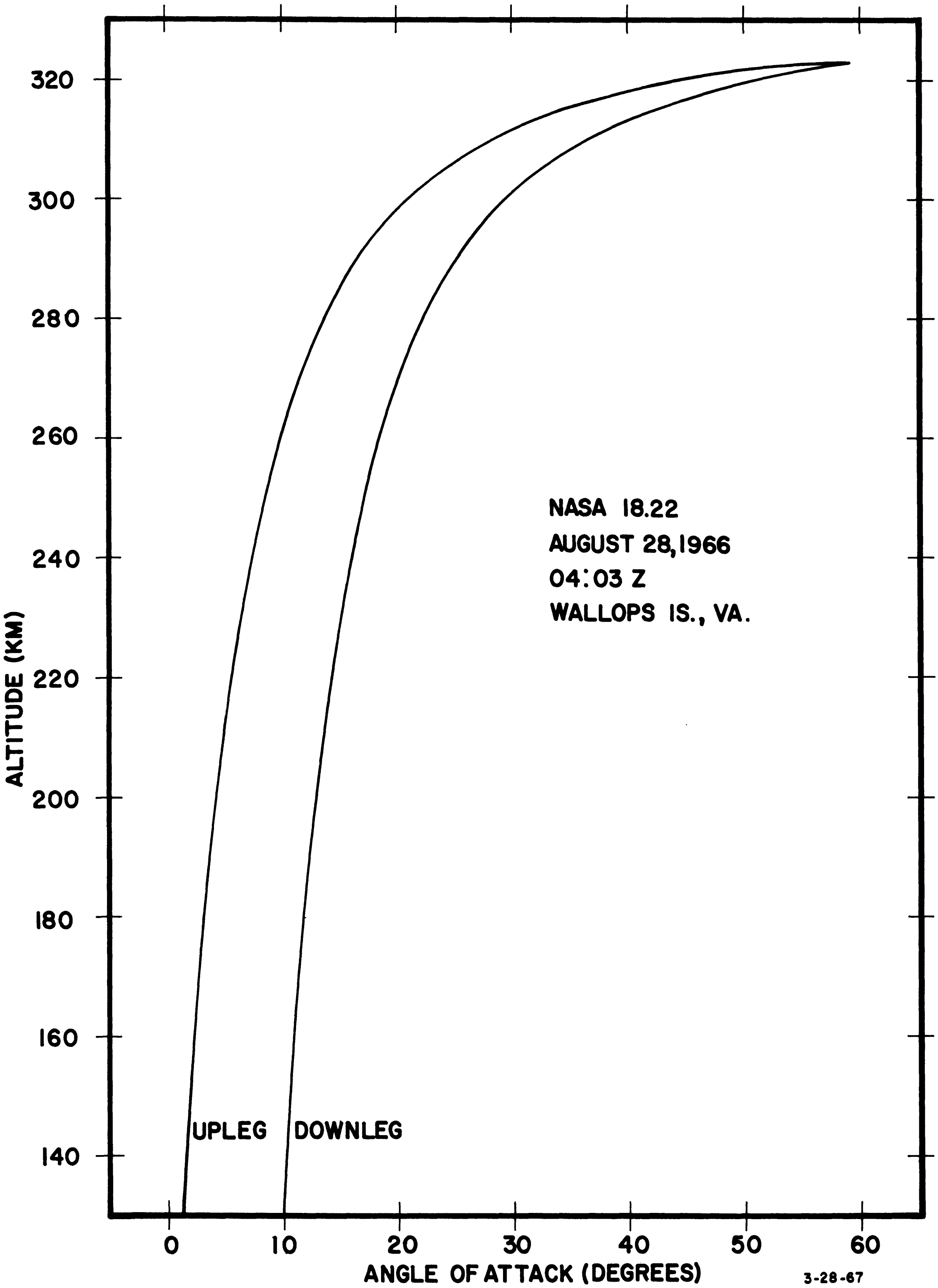

Figure 15. Angle of attack vs. altitude.

T_i = gauge wall temperature

V = vehicle velocity with respect to the earth

α = minimum angle of attack for one tumble

$K(S,\alpha)$ = correction factor required due to imperfect geometry (see Spencer, Taeusch, Carignan, 1966; also Niemann and Frederick, 1966).

ΔI_i, the difference between the maximum (peak) omegatron gauge current and the minimum (background) gauge current is shown vs. flight time in Figure 16. The background current is also shown in the figure. The background current is the result of the outgassing of the gauge walls and the inside density due to atmospheric particles which have high enough energy to overtake the TP and enter the gauge. The outgassing component is assumed constant for one tumble and effects both the peak reading and the background reading; and, therefore, does not effect the difference. From calibration data obtained by standard techniques, the inside number density, Δn_i, is computed for the measured current. As described by Spencer, Taeusch, and Carignan (1965), the uncertainty in these data is believed to be ±10.2% rms relative to other measurements using the same calibration system and ±25.1% rms absolute.

U_i, the most probable thermal speed of the particles inside the gauge, is computed using the measured gauge wall temperature shown in Figure 17. The uncertainty in this measurement is believed to be ±2.2% rms absolute.

V, the vehicle velocity with respect to the earth, is believed known to be better than ±1% absolute. It is obtained from the trajectory curve fitting described previously and is the most accurately known quantity obtained from the analysis.

Cos α is obtained from the aspect analysis described by Taeusch, et al. (1965). Since the uncertainty in cos α depends upon α, for any given error in α, each particular case and altitude range must be considered separately. As can be seen in Figure 15, the upleg data were obtained for angles of attack less than 7°, which results in an uncertainty in cos α of less than ±1% for an uncertainty in α of approximately ±5°. The upleg data were used as control data.

$K(S,\alpha)$ vs. altitude is shown in Figure 18. As can be seen, the maximum correction is about 12%, or $K(S,\alpha) = .88$ at about 140 km altitude for the upleg data. The correction factors, determined from empirical and theoretical studies, are believed known to better than 2%.

The resulting ambient N_2 number density, obtained from the measured quantities described above, is shown in Figure 19. The uncertainty in the ambient density due to the combined uncertainties in the measured quantities is ±10.7% rms relative and ±25.3% rms absolute.

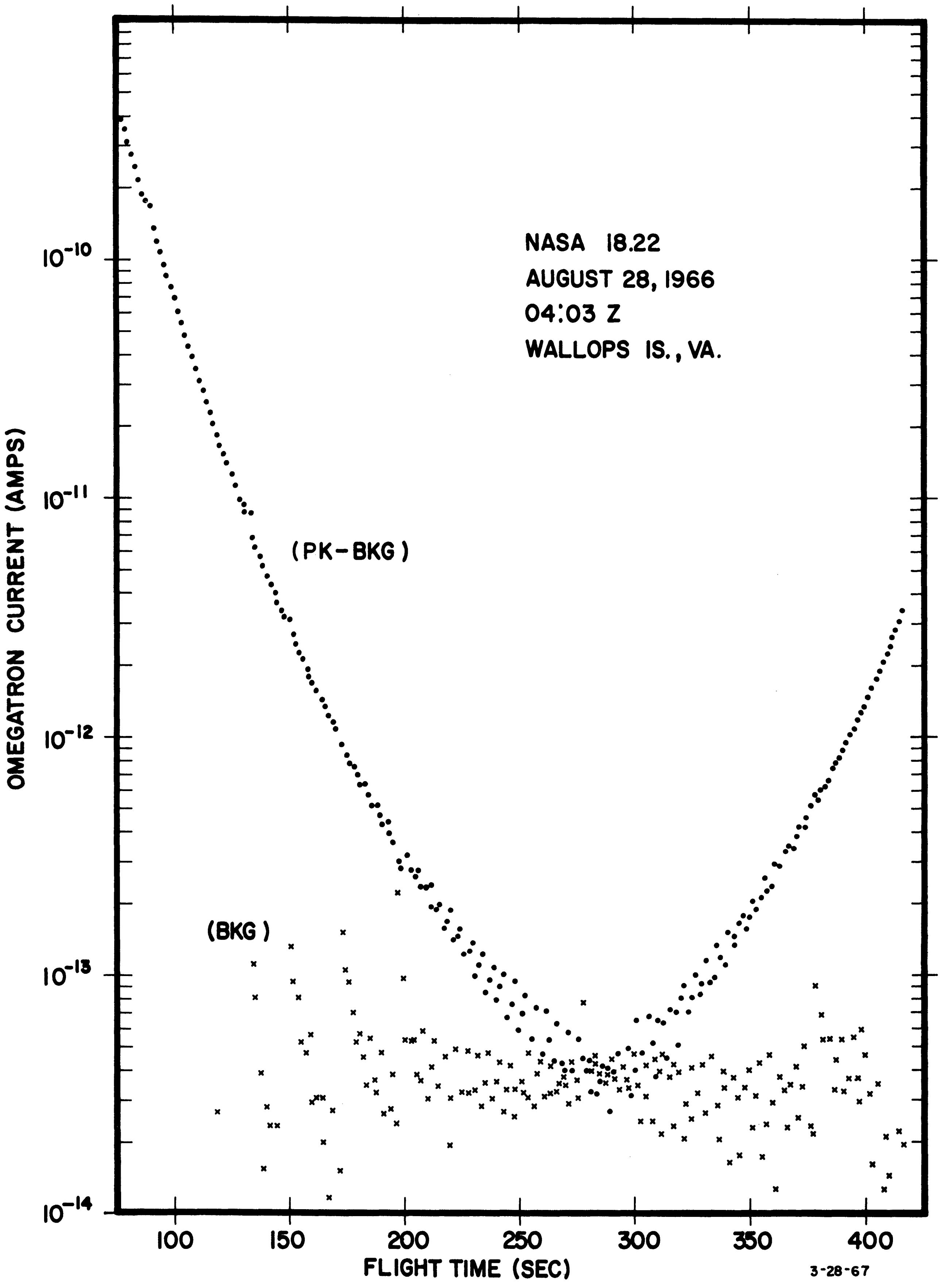

Figure 16. Δn_1 vs. flight time.

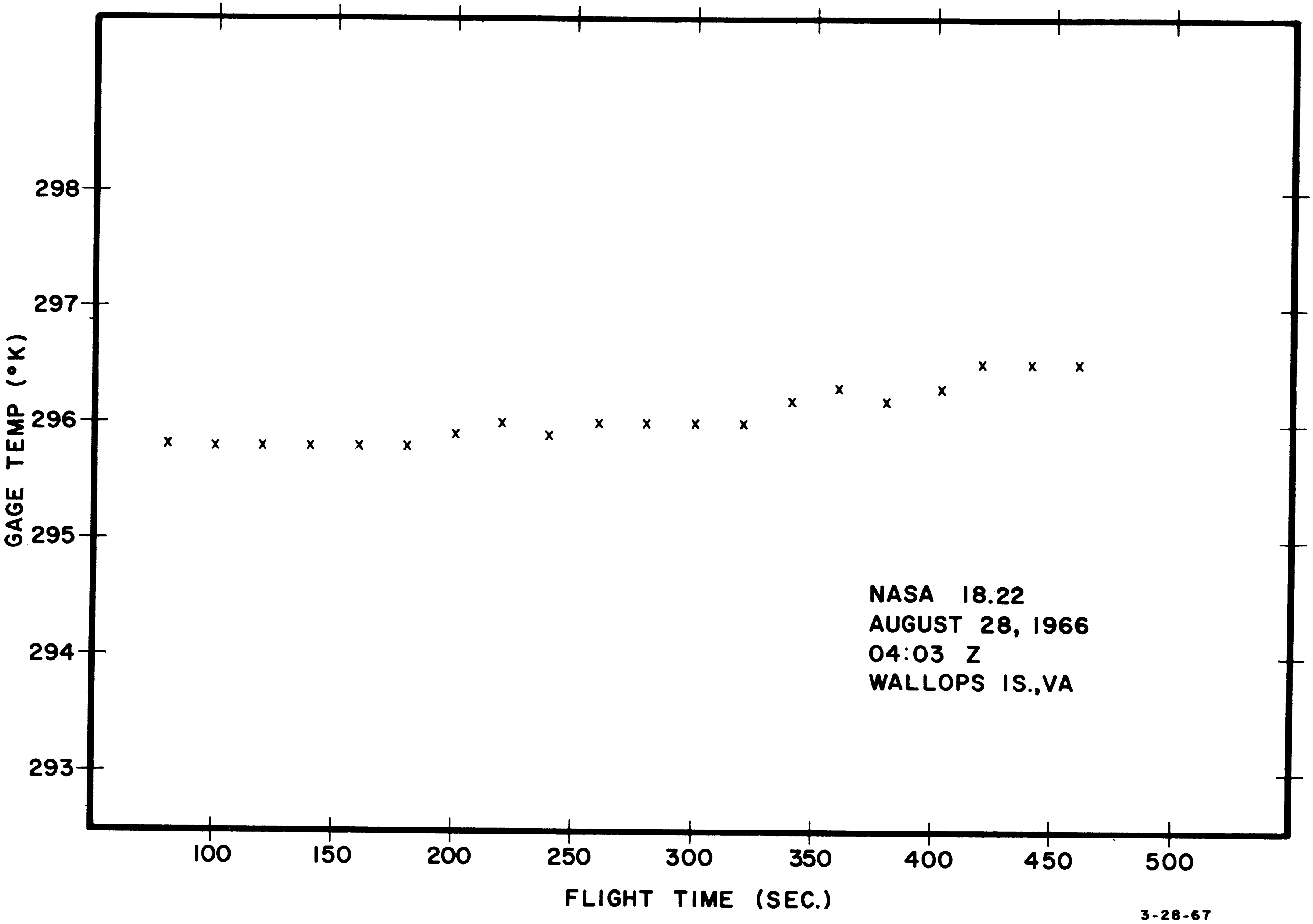

Figure 17. Gauge temperature vs. flight time.

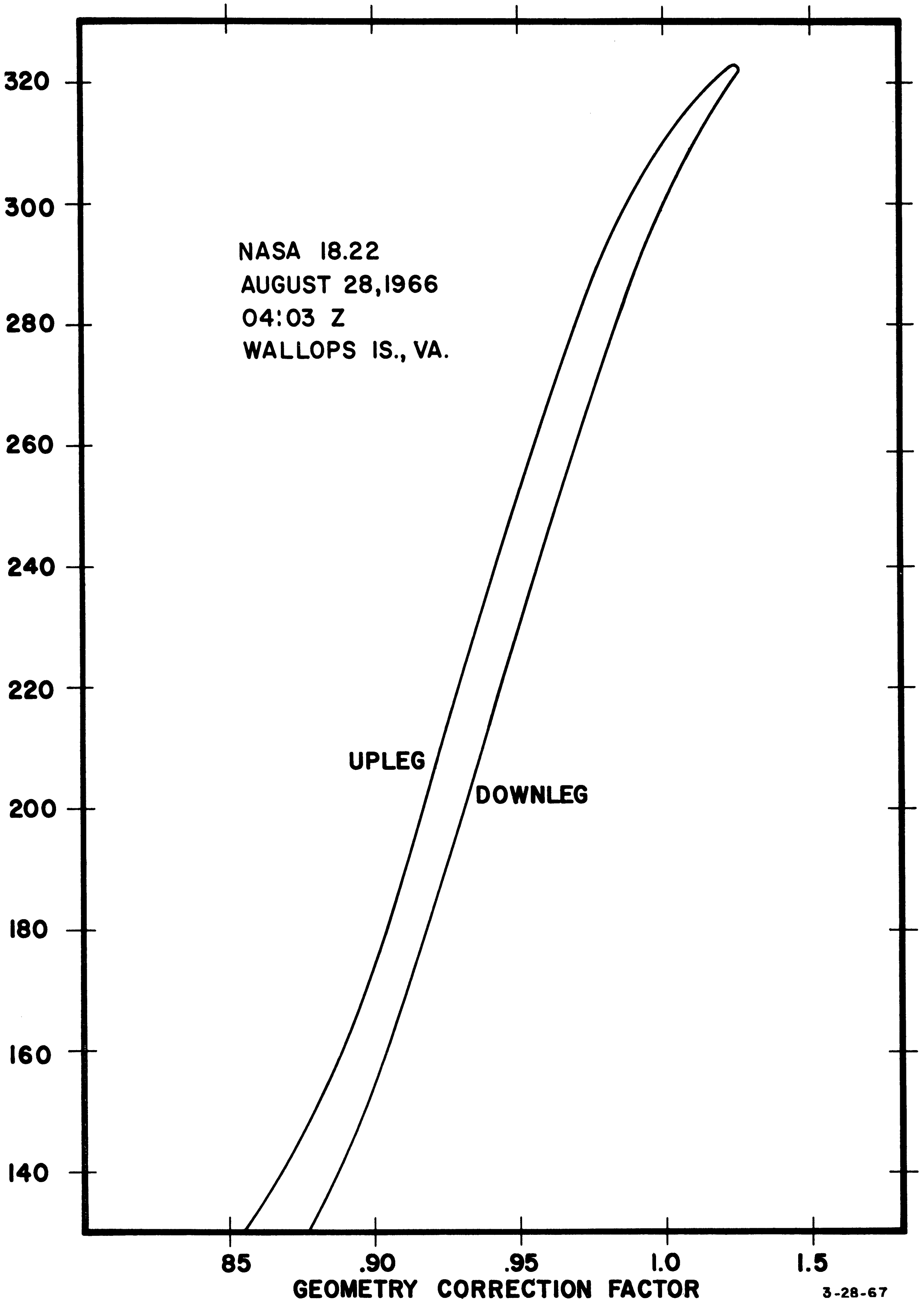

Figure 18. K(S,α) vs. altitude.

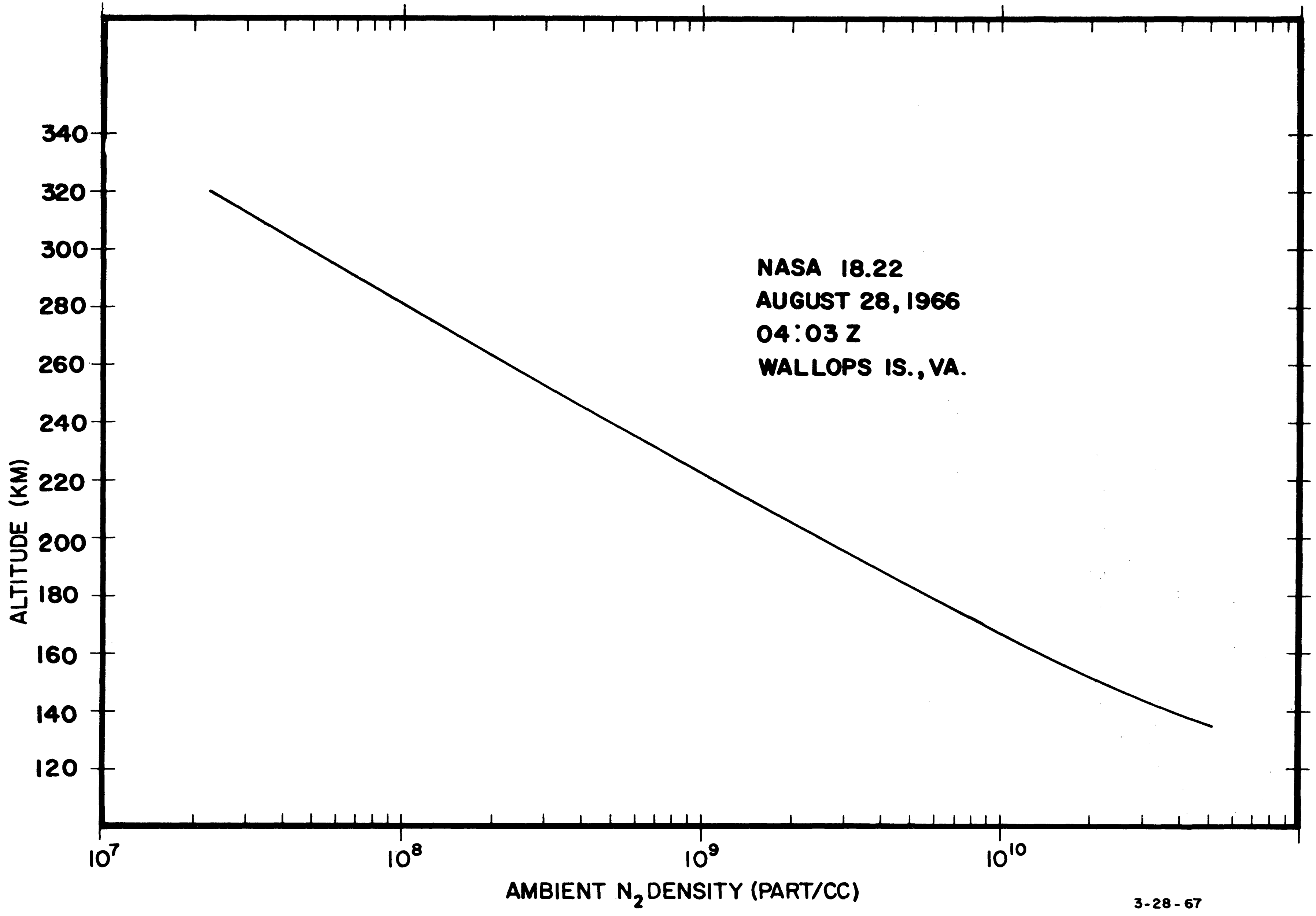

Figure 19. N_2 number density vs. altitude.

7.3 TEMPERATURE

The ambient N_2 temperature profile shown in Figure 20 was obtained by integrating the density profile to obtain the pressure and then relating the known density and pressure to the temperature through the ideal gas law. The assumption that the gas is in hydrostatic equilibrium and behaves as an ideal gas is implicit. Since the temperature depends only upon the shape of the density profile and not its magnitude, it is believed that the uncertainty in its magnitude is ±5% absolute.

7.4 CORRELATIVE DATA

The 10.7 cm solar flux and the geomagnetic activity indices are shown in Figures 21 and 22 for the appropriate periods preceding launch of the NASA 18.22 payload.

TABLE III

ATMOSPHERIC N_2 DATA

NASA 18.22
August 28, 1966
04:03 Z
Wallops Island, Va.

Altitude (km)	Temperature (°K)	Density (part/cc)
320	797	2.27×10^7
315	797	2.76
310	796	3.34
305	796	4.03
300	795	4.90
295	794	5.92
290	793	7.15
285	792	8.70×10^7
280	791	1.05×10^8
275	790	1.28
270	789	1.55
265	788	1.89
260	787	2.29
255	786	2.79
250	785	3.39
245	784	4.14
240	782	5.01
235	780	6.15
230	778	7.46
225	776	9.10×10^8
220	774	1.12×10^9
215	772	1.37
210	770	1.68
205	768	2.06
200	766	2.52
195	764	3.10
190	761	3.81
185	757	4.70
180	753	5.81
175	747	7.20
170	741	8.98×10^9
165	737	1.12×10^{10}
160	722	1.41
155	711	1.79
150	696	2.28
145	676	2.93
140	653	3.82
135	624	5.18×10^{10}

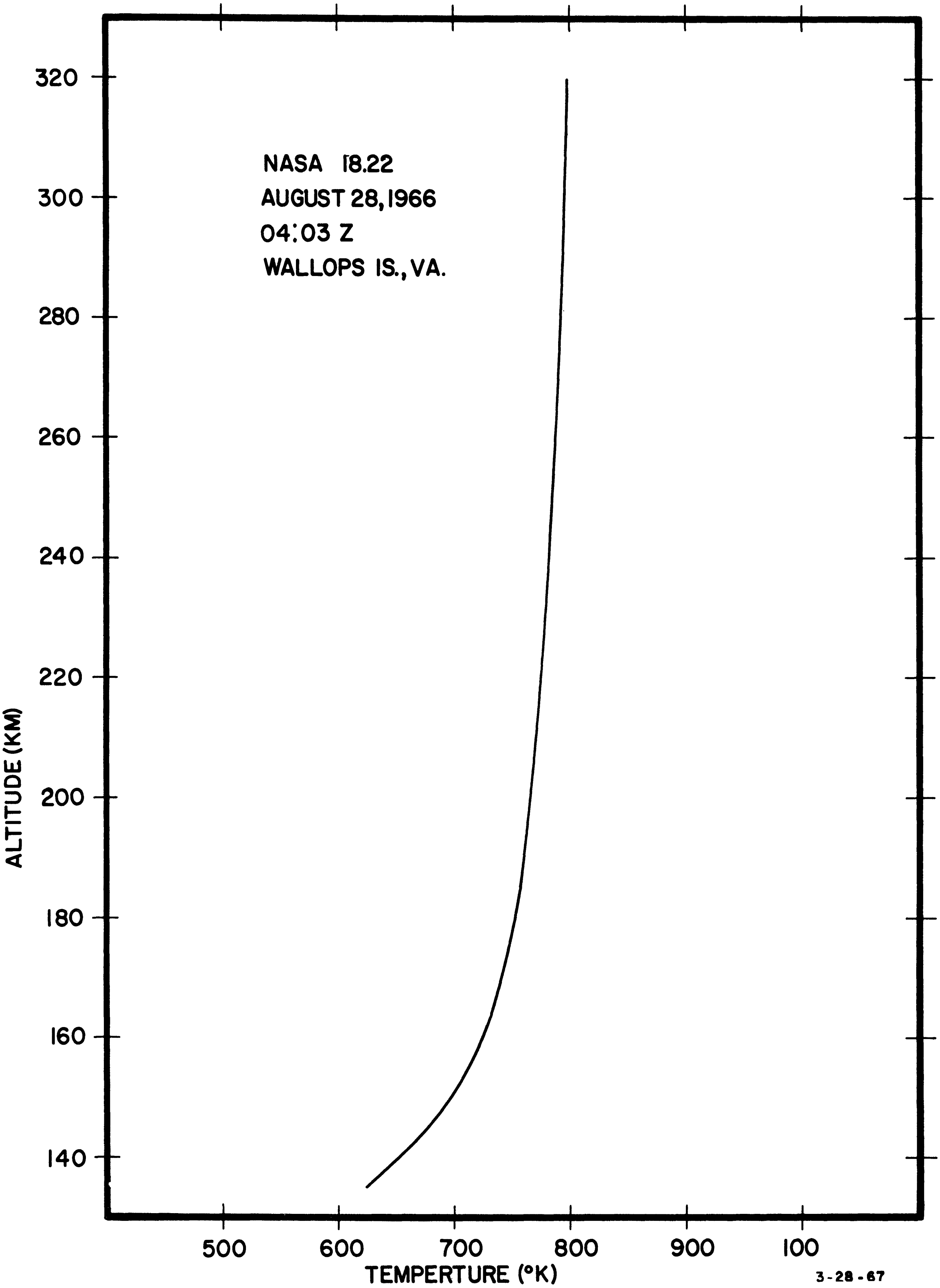

Figure 20. N_2 temperature vs. altitude.

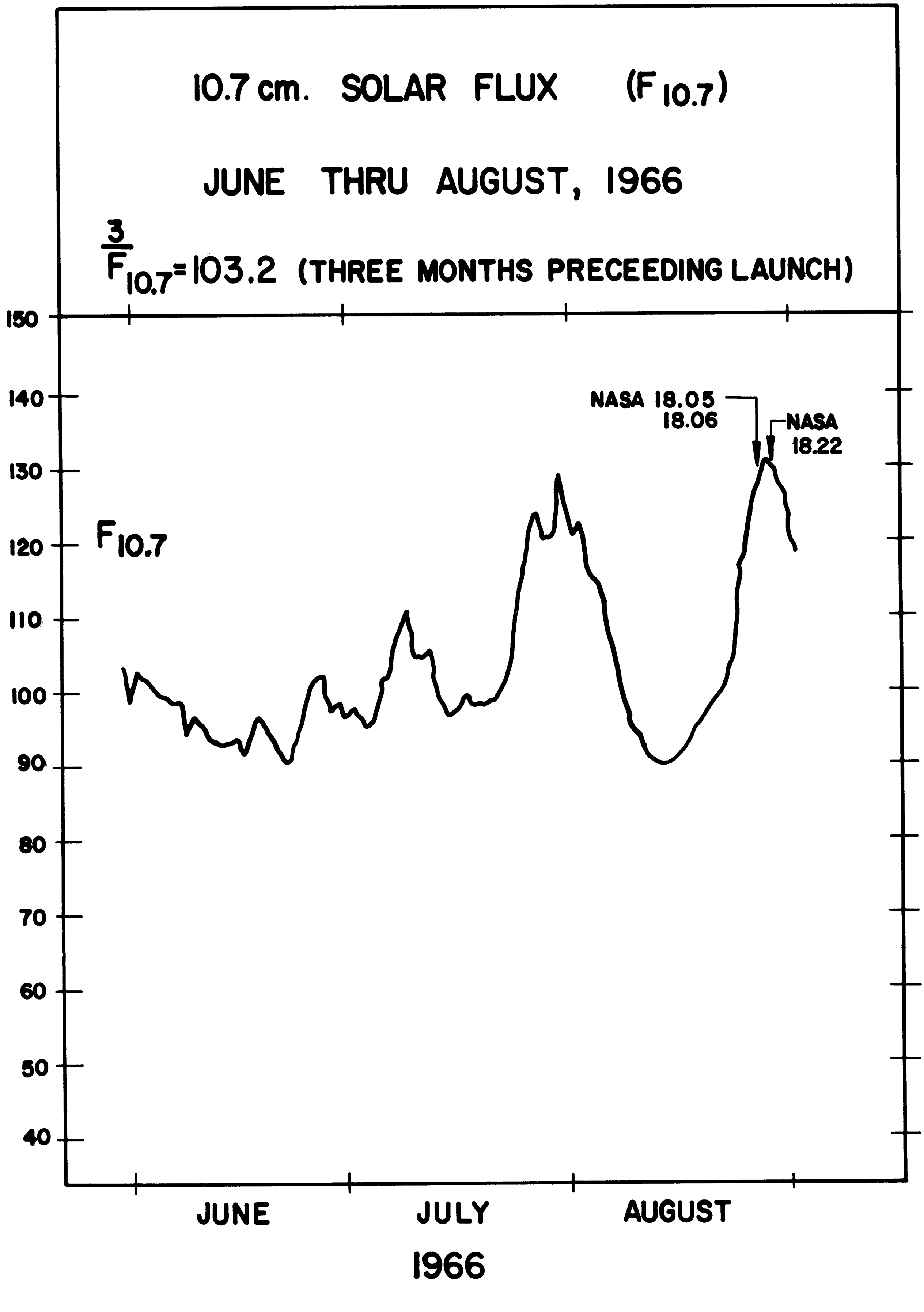

Figure 21. $F_{10.7}$ (10.7 cm solar flux) vs. time.

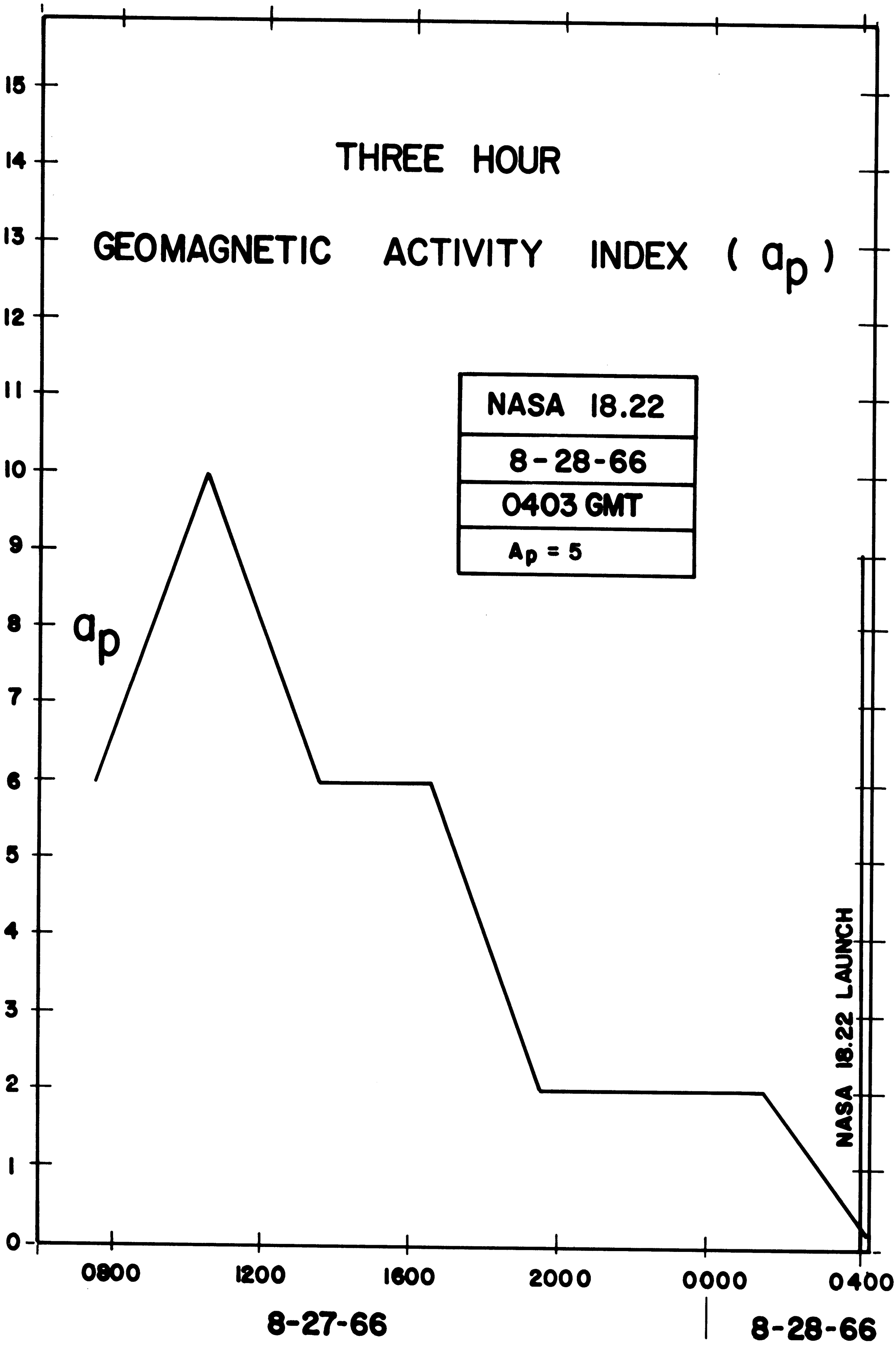

Figure 22. a_p vs. time.

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